Introduction of sociology-inspired parameters in the energy performance certification calculation method

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Abstract. One of the existing tools that could help creating *smart* energy policies is the Energy Performance Certification (EPC) of residential buildings, by introducing energy efficiency as a comparative criterion for real-estate purchase choices. It has been designed, at least, to influence real-estate market value, stimulate energy saving investments, move the housing market towards better energy efficiency and help create comprehensive databases which are fundamental for shaping smart strategies on urban / regional / national levels. But EPCs in their actual form, calculated with a standardized approach which purposefully (and understandably), gets human factor out of the equations, do not allow appropriation of the results by potential buyers or tenants. Often distant from reality, overestimating consumption, they usually result in a general misunderstanding and misuse of the document. This study aims at verifying that the actual calculation method used in certification could approach the objectives it has been designed for, by using additional data on occupants' behaviour and household characteristics. It first presents the two case studies of dwellings, and the additional data that has been gathered; the second part proposes a method to adapt the net heat demand calculation, and the comparative results between official (EPC) results, recalculated consumption evaluation and real consumption data.

1. Introduction

In order to reach energy efficiency at any level, human factor is crucial: on one hand, efficient solutions (regarding transport, building energy consumptions, water and waste management…) have to be implemented by an intelligent decision-making authority who understands the complexity of the urban context and its impacts on environment. On the other hand, smart cities authorities need smart citizens, who are aware of their environmental impact, to use smart solutions to their full potential. In the field of residential use of energy, people are therefore a crucial parameter of both the problem and its solution.

European Union's strategy for a sustainable growth makes the building sector energy consumption reduction a central objective for meeting the commitments taken under the Kyoto protocol on climate change. At a worldwide scale, this sector is thus regarded as one of the most cost-effective options for saving CO2 emissions (IPCC, 2007). To target the existing buildings potential, the European Union introduced (through the 2002/91/CE European Directive) Energy Performance Certificates (EPC), which should provide clear information about the energy performance of a building when it is sold or rented, including reference values, allowing performance comparisons between buildings. The EPC also includes "clear" recommendations for technically possible improvements, in order to increase investments in energy efficiency, move the housing market towards greater energy efficiency, influence real-estate market value and help built up comprehensive benchmarking databases, fundamental for shaping smart strategies on a local ('smart cities'), regional ('smart regions') and national level.

Given necessary standardization, the calculation method does not provide realistic results, and this is confirmed by energy bills; in theory, two different families living in two identical homes would receive identical EPCs, but in reality, their real consumption would vary from one to three or four (Hens, 2010), depending on occupants' behavior and household characteristics. As a consequence, crossing several studies that have been led in Belgium (Vanparys et al., 2012), the UK (Laine, 2011; O'Sullivan, 2007) or in Germany (Amecke, 2012) enlightens a general conclusion: the EPC is often considered unhelpful, unrealistic (and therefore mistrust), distant from reality, overestimating consumption, too long and technical, confusing…

Sociology of energy points the lack of appropriation of results as a missed opportunity. This study is therefore based on the assumption that, though acknowledging the importance of a standardized approach to allow building comparisons, other (and more accurate) results could be obtained from EPC inputs, by closing the gap between theoretical and real consumptions. A previous paper (Monfils, 2014) listed the uncertainty parameters of the EPC protocol and calculation method. It also proposed a method for the introduction of additional data (on the number of inhabitants, occupation patterns of the dwelling, levels and quality of electr(on)ic equipment and lighting) into a recalculation of internal gains and Domestic Hot Water (DHW) demand. This paper will propose to go further, with a re-evaluation of Net Heat Demand (NHD), based on extra information related to the dwellers' heating habits.

2. Hypotheses

2.1. Dwellings and households description

The study concentrates on two dwellings (Figures 1 and 2), an apartment in a small urban building and a row suburban house. We created, for these dwellings, an EPC with precision and respect to the regulation, then created "alternative" certificates by entering the calculation method and establishing different values for standardized parameters, in order to compare the results. Table 1 hereunder gathers some data describing the dwellings (parameters from the EPCs). Additional information may be found in (Monfils, 2014).

Figure 1. Apartment front façade and 3D model

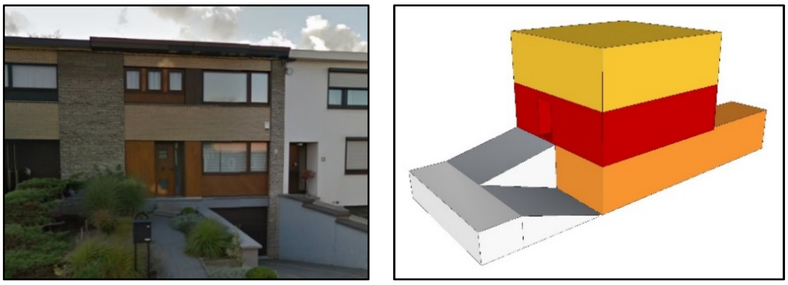

Figure 2. Row house front façade and 3D model

2.2. Tool

This study uses the regulatory EPC calculation method (Wallonia, 2013) provided by the Walloon public Administration in charge of the certification. With weather conditions being an important influence on the real consumption of dwellings, simulations have been made with climatic data for the region of Liege (where these dwellings are located), for the years 2010 – 2013 to compare the results with real consumption data for these years.

Table 1. Description of the dwellings

Data	Apartment	Row house
Heated volume (V_p)	330 m³	612 m³
Average U-value	2,2 W/m²K	1,2 W/m²K
Global heat η	51%	79%
DHW production η	40% (default)	75% (default)
Global DHW η	7% (hot water loop)	39% (default)
Number of inhabitants	1	4 (3)

2.3. Additional data

In order to “certify the building, not its users”, occupants’ behavior, comfort and building occupancy have been standardized in the official method: the whole dwelling is considered used and heated at all times, at a constant temperature of 18°C. Though permanent occupation increases internal loads, it also extends heating periods and, therefore, energy consumption. Reality, however, displays a wider range of behaviors: set temperatures and heating habits are bound to influence greatly the final energy consumption.

These information have been gathered from the dwellings owners. First, a series of 5 heating patterns (see Figure 3) were proposed to the owners, for them to characterize a typical winter week (indicating the number of days per week each pattern is used – 5 work days and 2 week-end days). The same patterns were used in (Monfils, 2014) to evaluate internal gains.

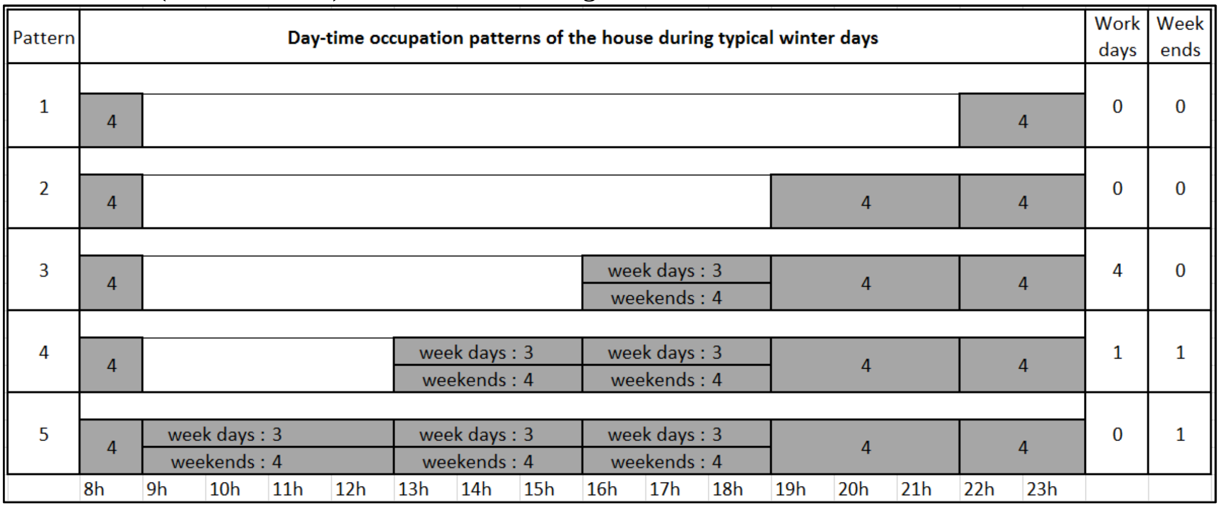

Figure 3. Occupation (and heating) patterns of the row house

A series of additional questions added extra information on:

- The repartition of heated rooms and their temperatures (if known) during each period of the patterns. This repartition can be seen on Figures 1 and 2; it displays day-time heated spaces (red), night-time heated spaces (yellow) and indirectly heated (orange).
- The presence of comfort control devices (thermostat, external probe), and their settings (such as set temperatures). These information allowed us to envision global temperature management or comfort-based manual control (mainly influencing set temperatures).
- The opening of spaces or staircases, to evaluate heat transfer between zones (mainly influencing the heat losses due to ventilation).
- The homogeneity of temperatures in considered zones
- The heating patterns during nights, in the absence of the occupants or in the bathroom

The results of this enquiry is visible in Table 2 hereunder.

Table 2. Data on behavior, heating and occupancy schedule and habits for the dwellings.

Additional data		Apartment	Row house
Global temperature management system?		No: Comfort-based management + thermostatic control	Yes: thermostatic control + thermostat + external probe
Annual heating period		October to April	October to April
Number of days (per week) for each pattern	1	1	0
	2	4	0
	3	0	4
	4	1	2
	5	1	1
Temperatures homogeneity?	Day zone	No[1]	Yes
	Night Zone	Yes (unheated)	Yes
Indirectly[2] heated spaces?		Yes[3]	Yes: basement[4]
Never[5] heated spaces?		No	No
Open plan of the day zone?		Yes	Yes
Open staircase between zones?		No staircase → yes	Yes
Open staircase to unheated spaces?		No staircase → no	Yes
Maximal set temperatures	Day zone	20°C[6]	21°C
	Night zone	-	21°C
	Bathroom	22°C	23°C
Minimal set temperatures	Day zone	-	16°C
	Night zone	-	16°C
	Bathroom	20°C	16°C

[1] Only the living room is heated; open plan indirectly helps heating circulations and kitchen

[2] Heated by adjacent rooms, without turning on the heating system in said room

[3] Circulations, kitchen and bedrooms, when living room heated + presence of (very) hot water pipes distributing heat and DHW in upper floors (4th floor is highest demanding apartment of the building)

[4] The son's bedroom has been considered indirectly heated during week days since 2011, as he integrated a boarding school

[5] Neither directly, nor indirectly

[6] Comfort-based manual control: by default set temperature

2.4. Additional hypotheses:

Average temperatures are calculated in due ratio to the zones volumes:

$$T_{set,i} = \frac{\sum_j T_{set,i,j} * V_{p,j}}{\sum_j V_{p,j}} \quad (1)$$

where:

- $T_{set,i}$ = average set temperature for the "i" period of the heating schedule [°C];
- $T_{set,i,j}$ = set temperature in "j" room, for the "i" period of the heating schedule [°C];
- $V_{p,j}$ = part of the protected volume occupied by the "j" room [%].

By hypothesis, temperature in Indirectly Heated Spaces (IHS) depends on the temperature of adjacent Directly Heated Spaces (DHS). In this study, the difference empirically equals 2°C when there are DHS on the same floor, 3°C when DHS are on the lower floor, and 4°C when DHS are on the upper floor.

Heat losses due to ventilation are considered at 100% of the official calculation method evaluation at all times during heated periods. This hypothesis takes into consideration that both dwellings present open spaces (and staircases for the houses), and that air tightness is a constant issue, as well as the inability in most dwellings to turn off a (almost) non existing ventilation system.

2.5. Net Het Demand Calculation

The official calculation method estimates the Net Heat Demand (NHD) by evaluating the monthly balance between heat losses (due to transmission, airtightness and ventilation) and the heat gains (due to occupation and solar radiation):

$$Q_{heat,net,m} = Q_{T,heat,m} + Q_{V,heat,m} - \eta_{util,heat,m} \left(Q_{i,m} + Q_{s,m}\right) \tag{3}$$

where:

- $Q_{heat,net,m}$ = NHD for the "m" month [MJ];
- $Q_{T,heat,m}$ = monthly heat losses due to transmission (overall protected volume envelope) [MJ];
- $Q_{V,heat,m}$ = heat losses due to airtightness and ventilation (overall protected volume) [MJ];
- $\eta_{util,heat,seci,m}$ = monthly heat gains application rate; a taming factor that reduces the internal and solar gains when they are less needed (depending on the losses/gains monthly ratio) to be kept in this proposition, as it translates a behavioral approach on comfort management.
- $Q_{i,m}$ = monthly internal gains [MJ], see (Monfils, 2014) for proposed evaluation method;
- $Q_{s,m}$ = monthly solar gains [MJ].

This NHD is then submitted to systems efficiencies (see Table 1) to evaluate final (and primary) energy consumptions. In this steady state calculation method, studying the influence of users' behavior can only pass through an adjustment of monthly heat losses via "real" dwelling occupancy schedule and heating habits data. The theory is to subdivide the protected volume in "heated zones", characterized by their own average comfort temperature during a predefined heated period, and the percentage of the global heat losses they generate.

The heat losses by transmission are evaluated as follows in the official method:

$$Q_{T,heat,m} = H_{T,heat} * \left(18 - \theta_{e,m}\right) * t_m \tag{4}$$

where:

- $Q_{T,heat,m}$= monthly heat losses through the envelope [MJ];
- $H_{T,heat}$: transmission heat losses coefficient [W/K];
- $\theta_{e,m}$= monthly average exterior temperature [°C];
- t_m= length of the month [Ms].

In order to integrate multiple time periods, with different set temperatures and heat loss coefficient, we can split the number of seconds in a month (t_m) between infinite terms, and NHD can therefore be split the same way:

$$Q_{T,heat,m} = \sum_{i=1}^{i=\infty} \alpha_i * H_{T,heat,m} * \left(T_{set,i} - \theta_{e,m}\right) * t_{m,i} \tag{6}$$

$$\alpha_i = \frac{\sum_j H_{T,heat,j}}{H_{T,heat}} \tag{7}$$

where…

- α_i = multiplicative factor for thermal losses by transmission for the "i" period [-];
- $T_{set,i}$ = average set temperature for the "i" period (see equation 1);
- $t_{m,i}$ = length of the "i" period [Ms];
- $H_{T,heat,j}$ = heat losses by transmission through the envelope of the "j" room, directly or indirectly heated during "i" period;

The heat losses through ventilation are evaluated the same way as shown in equation (6):

$$Q_{V,heat,m} = \sum_{i=1}^{i=\infty} \beta_i * H_{V,heat,m} * \left(T_{set,i} - \theta_{e,m}\right) * t_{m,i} \tag{8}$$

where β_i factors = 1 at all heated times. The values obtained for each dwelling are in Table 3:

Table 3. Parameters variation for the studied dwellings

Period		% of DHS in V_p	% of IHS in V_p	% of t_m	$T_{set,i}$ [°C]	α_i [%]	β_i [%]
Apartment	1	5%	0%	4,2%	22	0%	100%
	2	44,7%	55,3%	6,2%	19,1	100%	100%
	3	39,6%	60,4%	22,3%	18,7	100%	100%
	4	0%	0%	67,3%	NH[1]	0%	0%
Row house	1	32,2%	0%	33,3%	15,3	38,5%	100%
	2	62,1%	37,9%	30,7%	19,2	100%	100%
	3	62,1%	0%	14,6%	17,6	100%	100%
	4	0%	0%	21,4%	NH[1]	0%	0%

3. Results

The Tables 4 and 5 expose NHD and fuel consumption results for each dwelling for both official and proposed calculation methods (in this case, the result is the average of 2010 – 2013 simulations), as well as real consumption data (average of 2010 – 2013). Underneath, graphs (Figures 4 and 5) show the evolution of the comparison for the period 2010 – 2013.

The results show global improvements (with a reduction of the gaps between estimated and real consumption), as it was to be expected. But recalculated consumption is still 1,77 times the real consumption data for the apartment. This margin is still too important to overlook. It is far better in the row house case however (17% average margin); this can be explained by more precise and accurate input data in the calculation, for system efficiencies, for example.

The use of real annual climatic data is (globally) reflected in the real consumption data, except for the row house, where the 2013 variation still has to be explained. In the case of the apartment, the increase of real consumption in 2013 is explained by the owner as the year he renovated his kitchen, opening it to the rest of the apartment (which probably means it was better, though indirectly, heated).

Table 4. Results for the apartment

	[1] Official	[2] recalculated	[3] real	[1]/[3]	[1]/[2]	[2]/[3]
Net Heat Demand	12531 kWh	2917 kWh	-	-	4,3	-
Fuel consumption	39160 kWh	17404 kWh	9850 kWh	3,98	2,25	1,77

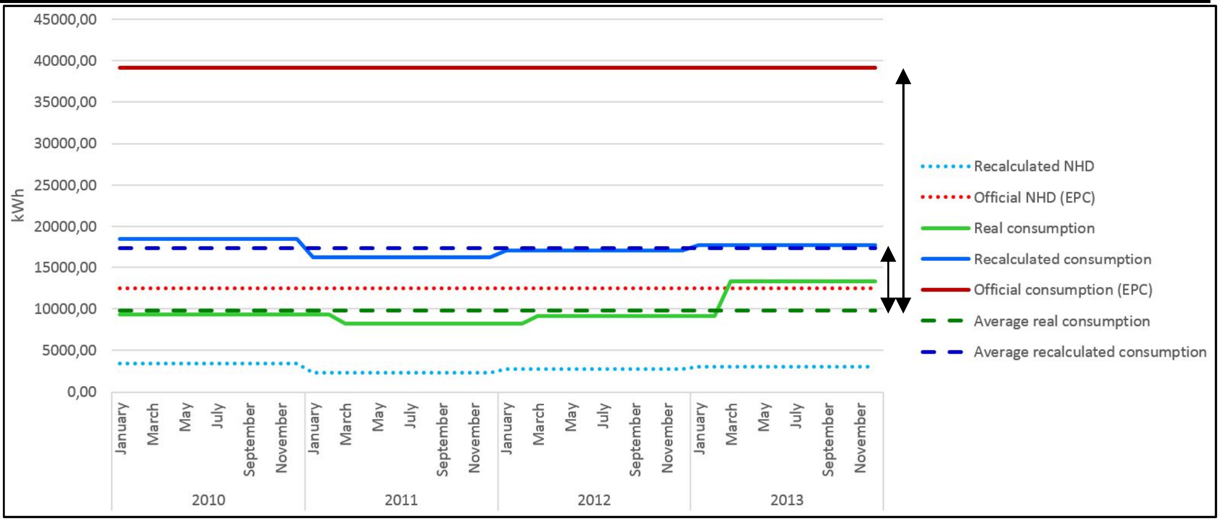

Figure 4. Evolution (2010 – 2013) of the comparison between official results, recalculated ones and real consumption data, for the apartment. The arrows indicate the differences between the average real consumption and the consumption estimations of both official and proposed calculation methods.

Table 5. Results for the row house

	[1] Official	[2] Recalculated	[3] Real	[1]/[3]	[1]/[2]	[2]/[3]
Net Heat Demand	29306 kWh	17507 kWh	-	-	1,67	-
Fuel consumption	39874 kWh	28495 kWh	24440 kWh	1,63	1,4	1,17

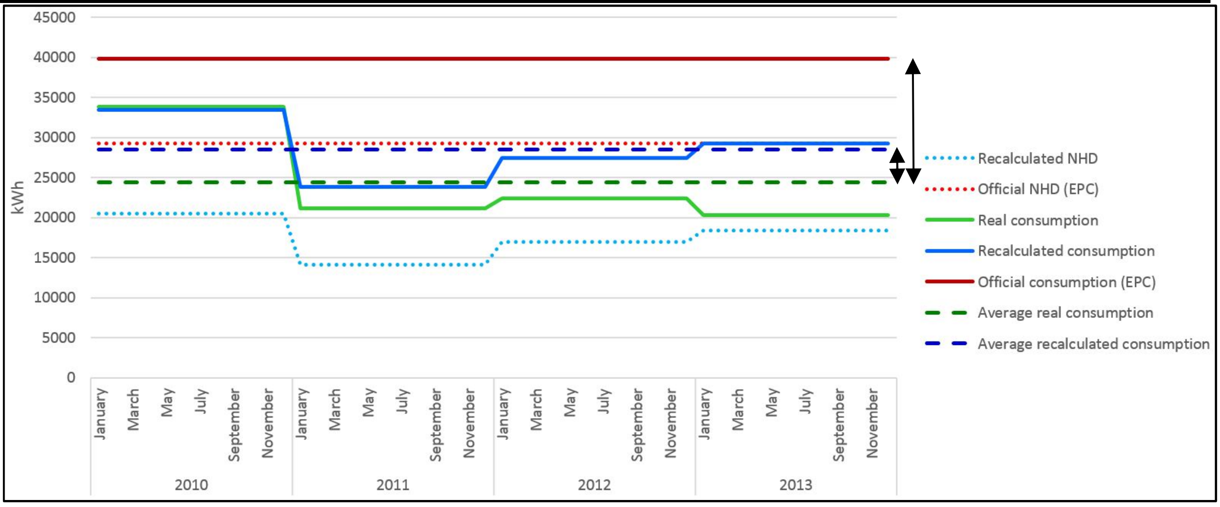

Figure 5. Evolution (2010 – 2013) of the comparison between official results, recalculated ones and real consumption data, for the row house. The arrows indicate the differences between the average real consumption and the consumption estimations of both official and proposed calculation methods.

4. Discussion and conclusion

The Energy Performance Certification is a great opportunity for monitoring and trying to improve the housing stock, for whoever wishes to reduce its energy consumption. But that potential remains underexploited. In order for the scheme to reach its goals and be used to penetrate the decision-making process of potential buyers or tenants, it is essential to find a way to make it understandable and understood, trusted and used by anybody. Though acknowledging the necessity of presenting a "legal" result as a comparison base, following the approved standardized calculation method, it is believed that other results could be displayed, based on the building characteristics and a minimum of behavioural inputs, creating a closer bond between future renters/owners and the results displayed in the EPC.

The creation of a complementary (not replacing) "custom-made" certification, for example, could help raise energy consumers' awareness of their energy consumption. The goal of this study was therefore to see if the existing data is usable, and the method strong enough for this purpose.

The great difficulty in this method is in two parts:

- The adaptation of a steady-state method, with a defined set of input data. Multi-zone dynamic calculations would obviously render more precise (and probably closer) results, but
- The remaining pool of unknown parameters, which influence grows in the balance when other inputs are refined. An enlightening example in this study stands in the default values that are attributed to heating and DHW systems efficiencies (see Table 1), according to their type and age, and induce obvious reservations towards consumption results. The part of the DHW-related consumptions dramatically increase when the system is granted by very low efficiencies, and even more so when the number of inhabitants increase also. Another example lays in the ventilation rates, as no data on actual rates could obviously be given by the owners.

However, it seems that, with a small amount of additional data (on the number of inhabitants, the set temperatures, the heating schedules), the certification calculation method would be strong enough to approach real consumption data. These results are encouraging, without entirely closing the gap. This is normal: the uncertainties of the Energy Performance Certificate approach are not all behaviour-related, but also stand in other specificities of the protocol, though the variation in quality of the EPC itself can be considered negligible here: the EPCs have been made by the same person, with this study in mind…

The next step of this study would be to try and validate the method, by a qualitative survey of heating habits in different typologies of housing, and use statistics to globalize coefficients precisely calculated here for both dwellings.

5. Acknowledgements

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